

SECTION 7.0

EMISSIONS FROM COMBUSTION SOURCES

The following stationary point and area combustion source categories have been identified as sources of benzene emissions: medical waste incinerators (MWIs), sewage sludge incinerators (SSIs), hazardous waste incinerators, external combustion sources (e.g., utility boilers, industrial boilers, and residential stoves and furnaces), internal combustion sources, secondary lead smelters, iron and steel foundries, portland cement kilns, hot-mix asphalt plants, and open burning (of biomass, tires, and agricultural plastic). For each combustion source category, the following information is provided in the sections below: (1) a brief characterization of the U.S. population, (2) the process description, (3) benzene emissions characteristics, and (4) control technologies and techniques for reducing benzene emissions. In some cases, the current Federal regulations applicable to the source category are discussed.

7.1 MEDICAL WASTE INCINERATORS

MWIs burn wastes produced by hospitals, veterinary facilities, crematories, and medical research facilities. These wastes include both infectious (“red bag” and pathological) medical wastes and non-infectious, general housekeeping wastes. The primary purposes of MWIs are to (1) render the waste innocuous, (2) reduce the volume and mass of the waste, and (3) provide waste-to-energy conversion. The total number and capacity of MWIs in the United States is unknown; however, it is estimated that 90 percent of the 6,872 hospitals (where the majority of MWIs are located) in the nation have some type of on-site incinerator, if only a small unit for incinerating special or pathological waste.¹⁹⁴ The document entitled *Locating and Estimating Air Toxic Emissions From Sources of Medical Waste Incinerators*, contains a

more detailed characterization of the MWI industry, including a partial list of the U.S. MWI population.

Three main types of incinerators are used for medical waste incineration: controlled-air, excess-air, and rotary kiln. Of the incinerators identified, the majority (>95 percent) are controlled-air units. A small percentage (<2 percent) are excess-air. Less than 1 percent were identified as rotary kiln. The rotary kiln units tend to be larger, and typically are equipped with air pollution control devices. Approximately 2 percent of the total population identified were found to be equipped with air pollution control devices.¹⁹⁵

7.1.1 Process Description: Medical Waste Incinerators¹⁹⁵

Controlled-Air Incinerators

Controlled-air incineration is the most widely used MWI technology and it now dominates the market for new systems at hospitals and similar medical facilities. This technology is also known as starved-air incineration, two-stage incineration, and modular combustion. Figure 7-1 presents a schematic diagram of a typical controlled-air unit.¹⁹⁵

Combustion of waste in controlled-air incinerators occurs in two stages. In the first stage, waste is fed into the primary, or lower, combustion chamber, which is operated with less than the stoichiometric amount of air required for combustion. Combustion air enters the primary chamber from beneath the incinerator hearth (below the burning bed of waste). This air is called primary or underfire air. In the primary (starved-air) chamber, the low air-to-fuel ratio dries and facilitates volatilization of the waste, and most of the residual carbon in the ash burns. At these conditions, combustion gas temperatures are relatively low (1,400 to 1,800°F [760 to 980°C]).

In the second stage, excess air is added to the volatile gases formed in the primary chamber to complete combustion. Secondary chamber temperatures are higher than

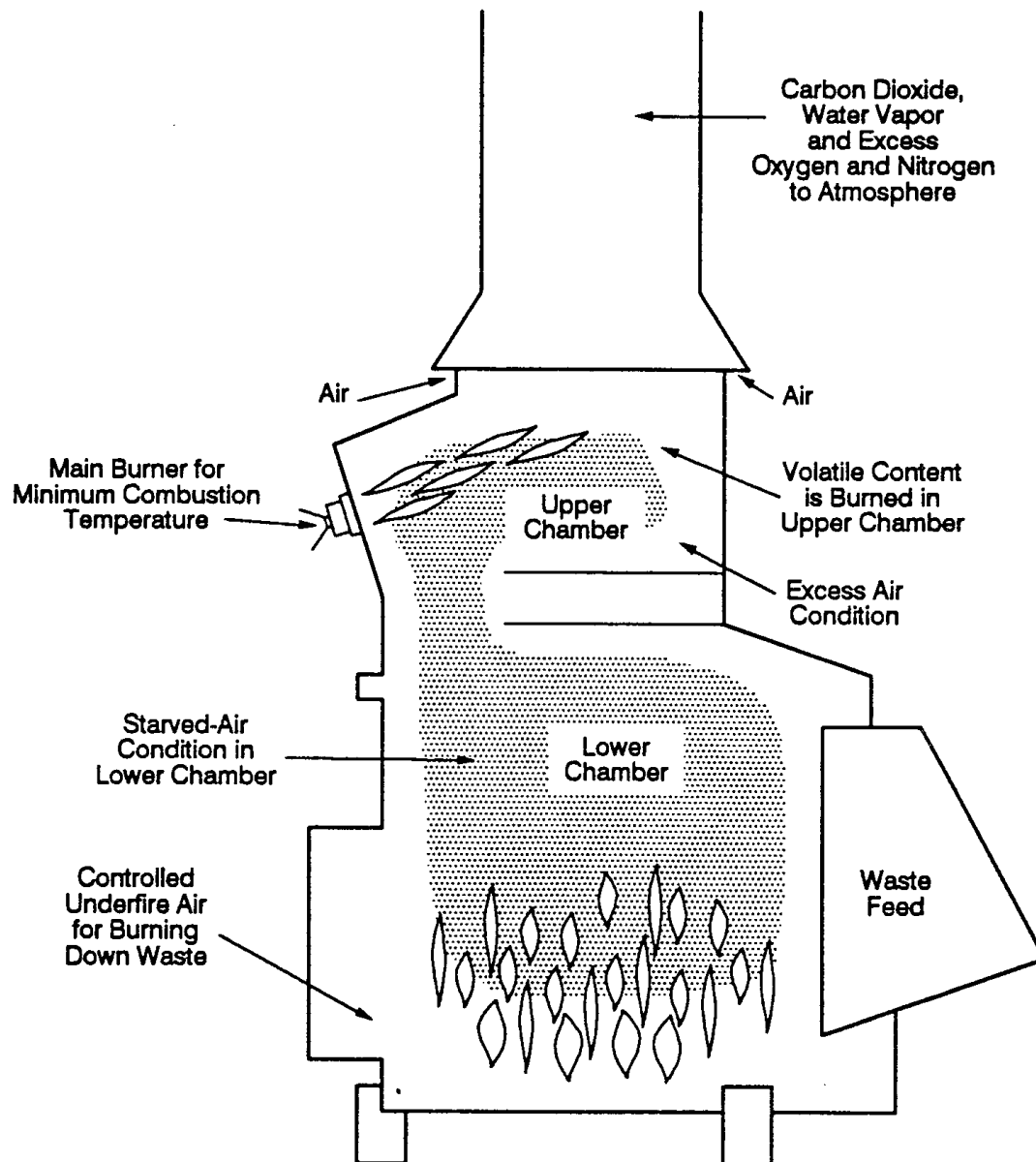


Figure 7-1. Controlled-Air Incinerator

Source: Reference 195.

primary chamber temperatures--typically 1,800 to 2,000°F (980 to 1,095°C). Depending on the heating value and moisture content of the waste, additional heat may be needed. This can be provided by auxiliary burners located at the entrance to the secondary (upper) chamber to maintain desired temperatures.

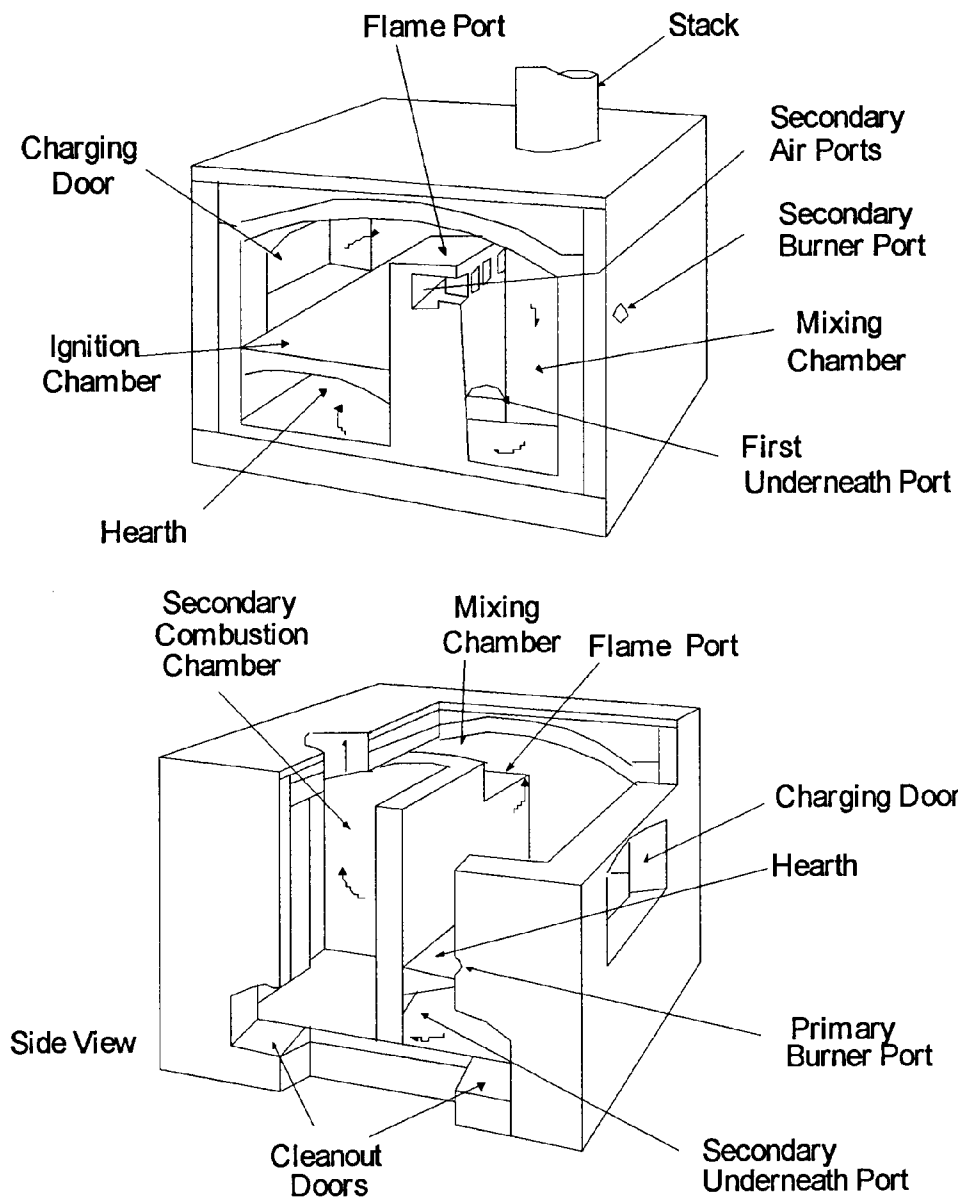
Waste feed capacities for controlled-air incinerators range from about 75 to 6,500 lb/hour (0.6 to 50 kg/min) (at an assumed fuel heating value of 8,500 Btu/lb [19,700 kJ/kg]). Waste feed and ash removal can be manual or automatic, depending on the unit size and options purchased. Throughput capacities for lower heating value wastes may be higher because feed capacities are limited by primary chamber heat release rates. Heat release rates for controlled-air incinerators typically range from 15,000 to 25,000 Btu/hr-ft³ (430,000 to 710,000 kJ/hr-m³).

Because of the low air addition rates in the primary chamber and corresponding low flue gas velocities (and turbulence), the amount of solids entrained in the gases leaving the primary chamber is low. Therefore, the majority of controlled-air incinerators do not have add-on gas cleaning devices.

Excess-Air Incinerators

Excess-air incinerators are typically small modular units. They are also referred to as batch incinerators, multiple-chamber incinerators, and “retort” incinerators. Excess-air incinerators are typically a compact cube with a series of internal chambers and baffles. Although they can be operated continuously, they are usually operated in a batch mode.

Figure 7-2 presents a schematic for an excess-air unit.¹⁹⁵ Typically, waste is manually fed into the combustion chamber. The charging door is then closed and an afterburner is ignited to bring the secondary chamber to a target temperature (typically 1,600 to 1,800°F [870 to 980°C]). When the target temperature is reached, the primary chamber burner ignites. The waste is dried, ignited, and combusted by heat provided by the primary



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Figure 7-2. Excess-Air Incinerator

Source: Reference 195.

chamber burner, as well as by radiant heat from the chamber walls. Moisture and volatile components in the waste are vaporized and pass (along with combustion gases) out of the primary chamber and through a flame port that connects the primary chamber to the secondary or mixing chamber.

Secondary air is added through the flame port and is mixed with the volatile components in the secondary chamber. Burners are also installed in the secondary chamber to maintain adequate temperatures for combustion of volatile gases. Gases exiting the secondary chamber are directed to the incinerator stack or to a control device. When the waste is consumed, the primary burner shuts off. Typically, the afterburner shuts off after a set time. After the chamber cools, ash is manually removed from the primary chamber floor and a new charge of waste can be added.

Incinerators designed to burn general hospital waste operate at excess air levels of up to 300 percent. If only pathological wastes are combusted, excess air levels near 100 percent are more common. The lower excess air helps maintain higher chamber temperature when burning high-moisture waste. Waste feed capacities for excess-air incinerators are usually 500 lb/hr (3.8 kg/min) or less.

Rotary Kiln Incinerators

Rotary kiln incinerators, like the other types, are designed with a primary chamber where the waste is heated and volatilized and a secondary chamber where combustion of the volatile fraction is completed. The primary chamber consists of a slightly inclined, rotating kiln in which waste materials migrate from the feed end to the ash discharge end. The waste throughput rate is controlled by adjusting the rate of kiln rotation and the angle of inclination. Combustion air enters the primary chamber through a port. An auxiliary burner is generally used to start combustion and maintain desired combustion temperatures. Both the primary and secondary chambers are usually lined with acid-resistant refractory brick. Refer to Figure 7-9 of this chapter for a schematic diagram of a typical rotary kiln incinerator. In

Figure 7-9, the piece of equipment referred to as the “afterburner” is the equivalent of the “secondary chamber” referred to in this section.

Volatiles and combustion gases pass from the primary chamber to the secondary chamber. The secondary chamber operates at excess air. Combustion of the volatiles is completed in the secondary chamber. Because of the turbulent motion of the waste in the primary chamber, solids burnout rates and particulate entrainment in the flue gas are higher for rotary kiln incinerators than for other incinerator designs. As a result, rotary kiln incinerators generally have add-on gas cleaning devices.

7.1.2 Benzene Emissions From Medical Waste Incinerators

There is limited information currently available on benzene emissions from MWIs. One emission factor for benzene emissions is provided in Table 7-1.¹⁹⁶ This factor represents benzene emissions during combustion of both general hospital wastes and pathological wastes.

7.1.3 Control Technologies for Medical Waste Incinerators

Most control of air emissions of organic compounds is achieved by promoting complete combustion by following good combustion practice (GCP). In general, the conditions of GCP are as follows:¹⁹⁴

- Uniform wastefeed;
- Adequate supply and good air distribution in the incinerator;
- Sufficiently high incinerator gas temperatures ($>1,500^{\circ}\text{F}$ [$>815^{\circ}\text{C}$]);
- Good mixing of combustion gas and air in all zones;
- Minimization of PM entrainment into the flue gas leaving the incinerator; and

TABLE 7-1. EMISSION FACTOR FOR MEDICAL WASTE INCINERATION

SCC	Emissions Source	Control Device	Emission Factor lb/ton (kg/Mg) ^a	Factor Rating
5-02-005-05	Incinerator	Uncontrolled	4.92 x 10 ⁻³ (2.46 x 10 ⁻³)	D

Source: Reference 196.

^a Emission factor is in lb (kg) of benzene emitted per ton (Mg) of medical waste incinerated.

- Temperature control of the gas entering the air pollution control device to 450 °F (230 °C) or less.

Failure to achieve complete combustion of organic materials evolved from the waste can result in emissions of a variety of organic compounds. The products of incomplete combustion (PICs) range from low-molecular-weight hydrocarbons (e.g., methane, ethane, or benzene) to high-molecular-weight organic compounds (e.g., dioxins/furans). In general, adequate oxygen, temperature, residence time, and turbulence will minimize emissions of most organics.

Control of organics may be partially achieved by using acid gas and PM control devices. To date, most MWIs have operated without add-on air pollution control devices. A small percentage (approximately 2 percent) of MWIs do use air pollution control devices, most frequently wet scrubbers and fabric filters. Fabric filters provide mainly PM control. Other PM control technologies include venturi scrubbers and electrostatic precipitators (ESPs). In addition to wet scrubbing, dry sorbent injection and spray dryer absorbers have also been used for acid gas (i.e., hydrogen chloride [HCl] and sulfur dioxide [SO₂]) control. Because it is not documented that acid gas/PM control devices provide reduction in benzene emissions from MWIs, further discussion of these types of control devices is not provided in this section. *Locating and Estimating Air Toxic Emissions From Sources of Medical Waste Incinerators*,¹⁹⁴ contains a more detailed description of the acid gas/PM air pollution control devices utilized for MWIs, including schematic diagrams.

7.1.4 Regulatory Analysis

Air emissions from MWIs are not currently regulated by Federal standards. However, Section 129 of the CAA requires that standards be established for new and existing MWIs. Standards for MWIs were proposed under Section 129 of the CAA on February 27, 1995 (38 FR 10654). Section 129 requires that the standards include emission limits for HCl, SO₂, and CO, among other pollutants. Section 129 also specifies that the standards may require monitoring of surrogate parameters (e.g., flue gas temperature). Thus,

the standards may require GCP, which would likely result in benzene emissions reduction. Additionally, the standards may require acid gas/PM control device requirements, which may result in some benzene emissions reduction.

7.2 SEWAGE SLUDGE INCINERATORS

There are approximately 170 sewage sludge incineration (SSI) plants operating in the United States. The three main types of SSIs are: multiple-hearth furnaces (MHF), fluidized-bed combustors (FBC), and electric infrared incinerators. Some sludge is co-fired with municipal solid waste in combustors, based on refuse combustion technology. Refuse co-fired with sludge in combustors based on sludge incinerating technology is limited to MHFs only.¹⁹⁷

Over 80 percent of the identified operating sludge incinerators are of the multiple-hearth design. About 15 percent are FBCs and 3 percent are electric infrared incinerators. The remaining combustors co-fire refuse with sludge. Most sludge incinerators are located in the Eastern United States, although there are a significant number on the West Coast. New York has the largest number of facilities, with 33. Pennsylvania and Michigan have the next largest number of facilities, with 21 and 19 sites, respectively.^{197,198} *Locating and Estimating Air Toxics Emissions for Sewage Sludge Incinerators* contains a diagram showing the geographic distribution of the existing population.¹⁹⁸

The three main types of sewage sludge incinerators are described in the following sections. Single hearth cyclone, rotary kiln, wet air oxidation, and co-incineration are also briefly discussed.

7.2.1 Process Description: Sewage Sludge Incinerators^{197,198}

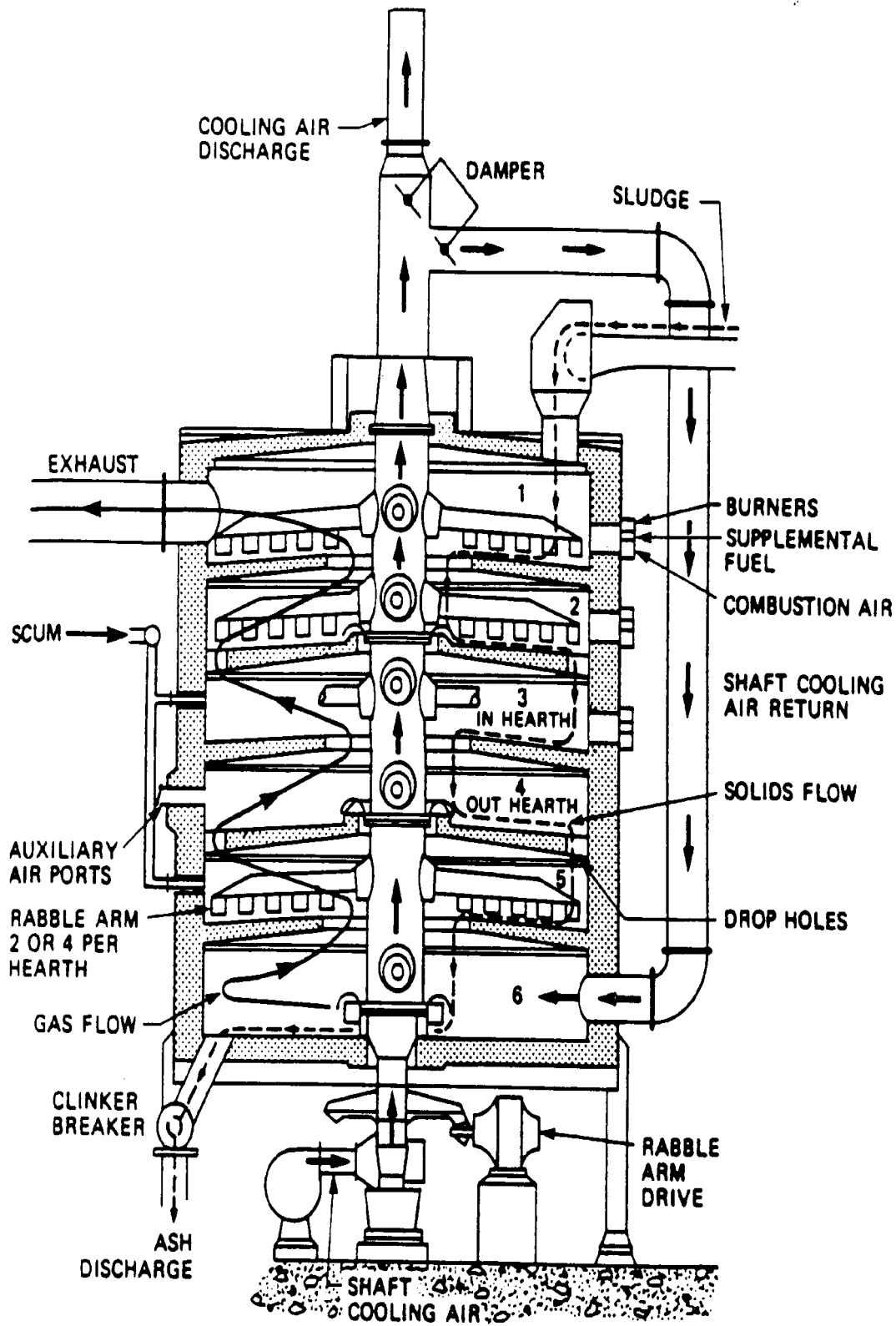
Multiple-Hearth Furnaces

A cross-sectional diagram of a typical MHF is shown in Figure 7-3.¹⁹⁸ The basic MHF is a vertically oriented cylinder. The outer shell is constructed of steel, lined with refractory, and surrounds a series of horizontal refractory hearths. A hollow cast-iron rotating shaft runs through the center of the hearths. Cooling air is introduced into the shaft, which extend above the hearths. Attached to the central shaft are the rabble arms, which extend above the hearths. Each rabble arm is equipped with a number of teeth approximately 6 inches in length and spaced about 10 inches apart. The teeth are shaped to rake the sludge in a spiral motion, alternating in direction from the outside in to the inside out, between hearths. Burners are located in the sidewalls of the hearths to provide auxiliary heat.

In most MHFs, partially dewatered sludge is fed onto the perimeter of the top hearth. The rabble arms move the sludge through the incinerator by raking the sludge toward the center shaft, where it drops through holes located at the center of the hearth. In the next hearth, the sludge is raked in the opposite direction. This process is repeated in all of the subsequent hearths. The effect of the rabble motion is to break up solid material to allow better surface contact with heat and oxygen. A sludge depth of about 1 inch is maintained in each hearth at the design sludge flow rate.

Scum may also be fed to one or more hearths of the incinerator. Scum is the material that floats on wastewater. It is generally composed of vegetable and mineral oils, grease, hair, waxes, fats, and other materials that will float. Scum may be removed from many treatment units, including pre-aeration tanks, skimming tanks, and sedimentation tanks. Quantities of scum are generally small compared to those of other wastewater solids.

Ambient air is first ducted through the central shaft and its associated rabble arms. A portion or all of this air is then taken from the top of the shaft and recirculated into



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Figure 7-3. Cross Section of a Multiple Hearth Furnace

Source: Reference 198.

the lower-most hearth as preheated combustion air. Shaft cooling air that is not circulated back into the furnace is ducted into the stack downstream of the air pollution control devices. The combustion air flows upward through the drop holes in the hearths, countercurrent to the flow of the sludge, before being exhausted from the top hearth. Air enters the bottom to cool the ash. Provisions are usually made to inject ambient air directly into the middle hearths as well.

Overall, an MHF can be divided into three zones. The upper hearth comprises the drying zone, where most of the moisture in the sludge is evaporated. The temperature in the drying zone is typically between 800 and 1,400 °F (425 and 760 °C). Sludge combustion occurs in the middle hearth (second zone) as the temperature is increased to 1,100 to 1,700 °F (600 to 930 °C). The combustion zone can be further subdivided into the upper-middle hearth, where the volatile gases and solids are burned, and the lower-middle hearth, where most of the fixed carbon is combusted. The third zone, made up of the lower-most hearth, is the cooling zone. In this zone, the ash is cooled as its heat is transferred to the incoming combustion air.

Under normal operating conditions, 50 to 100 percent excess air must be added to an MHF in order to ensure complete combustion of the sludge. Besides enhancing contact between fuel and oxygen in the furnace, these relatively high rates of excess air are necessary to compensate for normal variations in both the organic characteristics of the sludge feed and the rate at which it enters the incinerator. When the supply of excess air is inadequate, only partial oxidation of the carbon will occur, with a resultant increase in emissions of CO, soot, and hydrocarbons. Too much excess air, on the other hand, can cause increased entrainment of particulate and unnecessarily high auxiliary fuel consumption.

Fluidized-Bed Combustors

Figure 7-4 shows a cross-sectional diagram of an FBC.¹⁹⁸ FBCs consist of a vertically oriented outer shell constructed of steel and lined with refractory. Tuyeres (nozzles designed to deliver blasts of air) are located at the base of the furnace within a refractory-lined grid. A bed of sand, approximately 2.5 feet (0.75 meters) thick, rests upon the grid. Two